6 Estuary-Specific Age and Growth of Spotted Seatrout in the Northern Gulf of Mexico

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ABSTRACT

Age and growth of spotted seatrout collected from 1994 to 1996 were estimated from six bays along the panhandle of Florida: Perdido Bay, Pensacola Bay, Choctawhatchee Bay, St. Andrew Bay, St. Joseph Bay, and Apalachicola Bay. Age determinations were made using thin cross sections of sagittal otoliths. Annulus formation occurred during late winter to early spring; maximum observed ages for spotted seatrout were 5 to 9 for males and 5 to 8 for females. Female spotted seatrout generally grew larger and faster than males. Mean length at age 1 ranged from 296.3 to 340.8 mm FL for females and 264.7 to 310.5 mm FL for males. Mean length at age 3 ranged from 438.5 to 513.3 mm FL for females and 360.5 to 412 mm FL for males. Spotted seatrout data were fit to von Bertalanffy, Gompertz, and linear growth models. Sample sizes of older fish were small and did not fit well to nonlinear models. Differences in growth were determined by comparing slope and *y*-intercept of length-age linear regressions as well as comparing mean size-at-age. Male spotted seatrout length-age regressions were compared throughout the observed age range. Female regressions were compared through age 3.

Growth analyses showed that spotted seatrout displayed estuary-specific growth characteristics throughout the Florida Panhandle. There was no evidence of a geographic (east/west) trend in growth characteristics in the study area. Generally, spotted seatrout from St. Joseph Bay and Perdido

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Bay were larger and grew faster than those from other bays, while seatrout from Apalachicola and St. Andrew Bays generally grew slowest. The largest growth disparity was found between St. Joseph Bay and Apalachicola Bay, with discharges closer in proximity than other bays studied here.

INTRODUCTION

The euryhaline spotted seatrout, *Cynoscion nebulosus* (Cuvier), is associated with various estuarine habitats in bays, bayous, and lagoons from the Bay of Campeche, Mexico, north to Cape Cod (Tabb, 1966). Unlike most other sciaenids that reproduce offshore and utilize estuarine habitat primarily as a nursery, spotted seatrout tend to inhabit the estuary their entire lives. Moreover, individuals are generally nonmigratory, rarely traveling more than 50 km from their natal estuary (Moffet, 1961; Iversen and Tabb, 1962; Baker et al., 1986; Overstreet, 1983; Baker and Matlock, 1993).

The spotted seatrout has attracted much attention in the scientific community in recent years (Bortone et al., 1997) because it supports an important inshore recreational fishery along much of the U.S. South Atlantic and Gulf of Mexico coasts. Florida accounts for nearly 55% of all landings, with the majority of those from counties bordering the Gulf of Mexico (communication from the National Marine Fisheries Service, Fisheries Statistics and Economics Division). In 1955, commercial and recreational spotted seatrout fisheries began to decline in Florida (Tabb, 1961). Continuing with this trend, commercial harvest in Florida averaged 1.59 million kg from 1961 to 1970 and declined to 1.17 million kg from 1971 to 1980 and to 0.68 million kg during the 1980s (communication from the National Marine Fisheries Service, Fisheries Statistics and Economics Division). While catches were declining, widespread coastal development reduced habitat for spotted seatrout; in less developed areas of the state, lack of a minimum size limit allowed fish to be harvested before they reached maturity (Muller, 1997).

Regulation of spotted seatrout populations, each as a separate unit stock, was suggested in the 1960s (Moffet, 1961; Iversen and Tabb, 1962). Reports of genetically discrete populations of spotted seatrout, however, have been controversial. Some maintain that each estuary contains distinct populations of spotted seatrout (Weinstein and Yerger, 1976), while others argue that genetic isolation occurs only over long distances (Ramsey and Wakeman, 1987; King and Pate, 1992; Wiley, 1996). Gold et al. (1999) present evidence that both features are found among spotted seatrout populations. Importantly, however, regional differences in certain biological attributes of spotted seatrout, such as growth rate, age at maturity, and longevity, have repeatedly been reported (Pearson, 1929; Moody, 1950; Moffet, 1961; Tabb, 1961; Iversen and Tabb, 1962; Maceina et al., 1987; Cottrell, 1990; Murphy and Taylor, 1994).

Differences in age, growth, maturity, and mortality reported for various populations of spotted seatrout require that estuary-specific information regarding growth rates and age composition be obtained to manage the spotted seatrout fishery effectively. Our purpose here is to demonstrate the potential for separate stock recognition between proximate estuaries by providing estuary-specific information on age and growth of spotted seatrout populations in the northern Gulf of Mexico from the Panhandle region of Florida.

METHODS

Data for this study were collected from May 1994 through August 1996 in the six westernmost estuaries in Florida; from west to east, these are Perdido Bay, Pensacola Bay, Choctawhatchee Bay, St. Andrew Bay, St. Joseph Bay, and Apalachicola Bay (Figure 6.1). The sampling periods for each bay system were as follows:

Perdido Bay: May 1995 through July 1996
Pensacola Bay: May 1994 through April 1995
Choctawhatchee Bay: May 1995 through June 1996

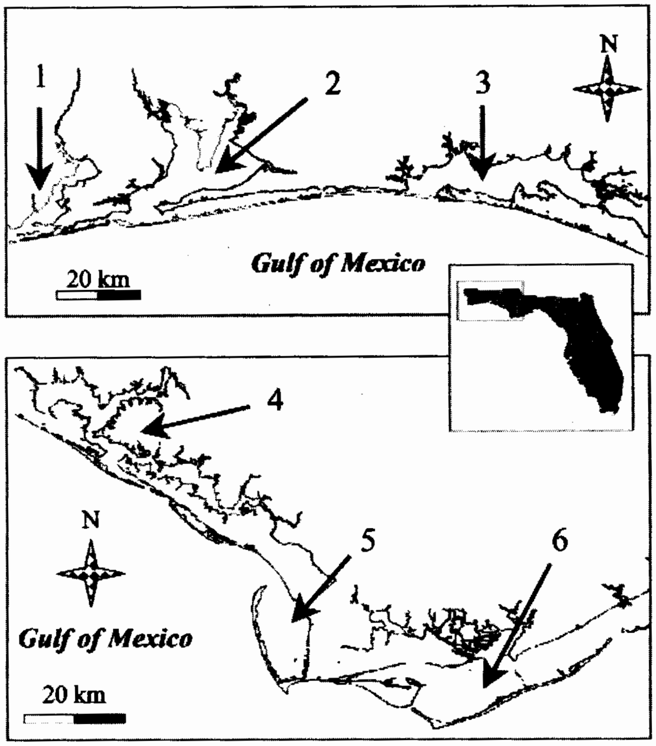

FIGURE 6.1 Study area. The top section displays the bay systems in the western half of the study area; from west to east, they are Perdido Bay (1), Pensacola Bay (2), and Choctawhatchee Bay (3). The bottom section indicates the eastern half of the study area; from west to east, the bay systems are St. Andrew Bay (4), St. Joseph Bay (5), and Apalachicola Bay (6).

St. Andrew Bay: May 1994 through November 1995
St. Joseph Bay: April 1995 through August 1996
Apalachicola Bay: April 1995 through August 1996

Spotted seatrout from Pensacola and St. Andrew bays were collected by hook and line, by a 79-mm stretch mesh gill net, and from monthly tournaments held by local hook and line clubs. A commercial fisher also provided fish harvested with a 91-mm stretch mesh gill net from Pensacola Bay. Spotted seatrout were collected from Perdido Bay and Choctawhatchee Bay using hook and line and a 79-mm stretch mesh gill net and from St. Joseph Bay and Apalachicola Bay using hook and line only. Many specimens collected from Apalachicola Bay were obtained from local fishing guides.

Upon capture, specimens were immediately put on ice. Fork length (FL) to the nearest millimeter and total body weight to the nearest gram were recorded within 24 hours of capture. Sex of small fish (< 250 mm FL) was determined via microscopic squash examination of gonadal tissue sections. Sex of all other individuals was determined macroscopically. Both otoliths (sagittae) were extracted and stored dry. Sections (approximately 0.5 mm thick) of otoliths were prepared using a Beuhler® Isomet, low-speed saw. Sections were mounted on glass slides using Baxter® S/P Pro-Texx mounting medium and later polished using 400- and then 600-grit sandpaper.

The otolith sections from Perdido, Pensacola, and Choctawhatchee specimens were read for age by Bedee three times. Readings were performed twice using a compound microscope at 40× magnification and once using the Optimas® image analysis system at 75×. Otoliths from which the age determination did not agree after the third analysis were discarded. The otolith sections from St. Andrew, St. Joseph, and Apalachicola specimens were read twice by Palmer with a compound microscope at 40×. All sections were read without knowledge of fish length, time of capture, or previous age determination. Age was determined by the number of complete annuli appearing on otolith sections. Annuli were identified as thin, opaque bands and were considered complete if distinct along the distal edge of the sacculus groove and at least faintly visible along the remainder of the distal edge (Figure 6.2).

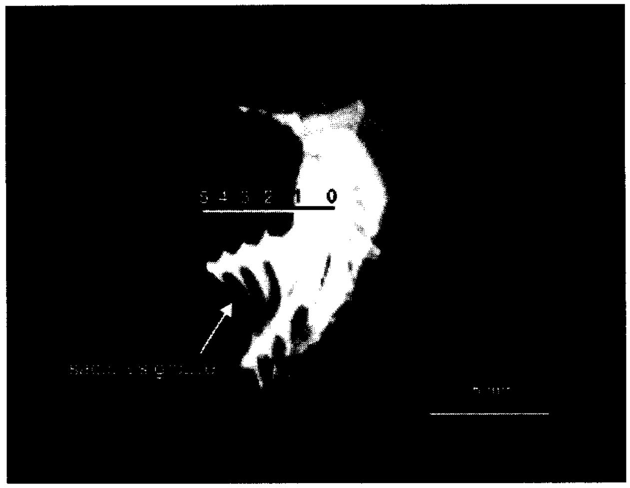

FIGURE 6.2 Sectioned view of a sagittal otolith extracted from an age 5 spotted seatrout.

Validation of annuli formation for spotted seatrout from Perdido Bay, Pensacola Bay, and Choctawhatchee Bay was accomplished indirectly by marginal increment analysis. Annulus measurements were recorded to the nearest micrometer (μm) from the center of the otolith (i.e., nucleus) to the distal edge of each annulus. The measurements were recorded consistently along a designated line from the nucleus center, distally to the lateral edge of the otolith section, and were aided using the Optimas® image analysis system. The mean marginal increment (i.e., the measured increase in otolith radius since the most recent annulus formation) for all fish was then plotted vs. month of capture. Time of annulus completion was determined by identifying the months with the lowest mean marginal increment.

Validation of annuli formation for spotted seatrout from St. Andrew, St. Joseph, and Apalachicola bays was accomplished indirectly by proportional estimates of marginal otolith growth. Marginal increment (MI) growth of each sagittal otolith section was given a value of 0.3, 0.6, and 0.9, based on whether the incremental growth since the most recent annulus was less than $^1/_3$, greater than $^1/_3$ and less than $^2/_3$, or greater than $^2/_3$ of the distance between the previous two annuli, respectively. Those values of MI were then plotted vs. month of capture. Annulus formation was determined by identifying months with lowest mean values of MI. This method was used to validate annuli because an image analysis system was unavailable.

January 1 was considered the birthdate for all fish. Fish collected after April 1 (April corresponds to the onset of spawning as well as annulus formation) but before January 1 of a given year were placed in an age class corresponding to the number of annuli. Fish collected between January 1 and April 1 were placed in an age class corresponding to the number of observed annuli plus 1, with the exception of the few fish that laid down new annuli between January 1 and April 1.

Age-class 0 fish were assigned an age value of 0.5 years when fitting data to growth models. This value was based on a conservative estimate of actual age in months of spotted seatrout hatched between May and September and harvested between October and February. More than one model (i.e., von Bertalanffy, Gompertz, and linear) have been used to describe spotted seatrout growth (Maceina et al., 1987; Cottrell, 1990; Murphy and Taylor, 1994). Spotted seatrout data from this study were fitted to each model previously used to describe spotted seatrout growth.

For the purpose of comparing growth of spotted seatrout among estuaries, we chose to define growth in two ways. The first method compared growth as an increase in length (FL) over time, using length–age linear regressions. Differences in length–age slopes were compared using students' t-tests of the linear regression slopes followed by t-tests for differences in elevation for those pairs with equal slopes (Zar, 1996). This method was used instead of comparing asymptotic growth curves because of the paucity of older fish collected, the wide asymptotic confidence intervals observed for L_∞ estimates, and an apparent lack of asymptote for male length–age relationships. Female age–length relationships were compared through age 3, while growth of male spotted seatrout was compared across the entire observed age range. The second method simply compares mean size at age (Francis, 1996). Mean lengths (FL) of spotted seatrout at ages 1, 2, and 3 were compared among estuaries using bootstrap, resampling analyses (Westfall et al., 1999). A significance level of $P \leq .05$ was used to evaluate statistical tests throughout.

RESULTS

A total of 3711 spotted seatrout were collected during the study period. Perdido Bay yielded 219 seatrout, 586 were collected from Pensacola Bay, 362 from Choctawhatchee Bay, 1204 from St. Andrew Bay, 561 from St. Joseph Bay, and 778 from Apalachicola Bay. The smallest spotted seatrout was a 171-mm FL female collected from St. Joseph Bay; the largest was a 790-mm FL female from Pensacola Bay. In general, female spotted seatrout were larger at age than males. Lengths (FL) of females had the following ranges (see Table 6.1):

202 to 624 mm (Perdido Bay)
235 to 790 mm (Pensacola Bay)
201 to 614 mm (Choctawhatchee Bay)
198 to 715 mm (St. Andrew Bay)
171 to 721 mm (St. Joseph Bay)
217 to 593 mm (Apalachicola Bay)

Lengths (FL) of male spotted seatrout (see Table 6.2):

220 to 472 mm (Perdido Bay)
203 to 543 mm (Pensacola Bay)
221 to 489 mm (Choctawhatchee Bay)
180 to 586 (St. Andrew Bay)
201 to 536 (St. Joseph Bay)
230 to 506 (Apalachicola Bay)

Agreement between the first two trials of age determination was 91% for Perdido Bay, Pensacola Bay, and Choctawhatchee Bay. Agreement in age determination from St. Andrew, St. Joseph, and Apalachicola bays was over 95%. This can be compared to other recent age-determination studies using spotted seatrout otoliths. Maceina et al. (1987) attained 99% agreement between first and second readings, and Murphy and Taylor (1994) had agreement of 88%. Disagreement in our study was attributable to a poorly prepared otolith section or, more commonly, to difficulty in distinguishing the presence of a new annulus.

Analysis of marginal increments indicated that spotted seatrout in the Florida Panhandle form a new opaque band on sagittal otoliths each year. Maximum marginal increment occurred in late fall and early winter months. Mean marginal increment was minimal for all bays in March and April, indicating that annuli form in late winter and are completed by spring (Figure 6.3). A new complete annulus was evident in 13 fish (seven from Perdido Bay, five from Pensacola Bay, and one from Choctawhatchee Bay) as early as January, and all fish showed marginal increment growth by May.

Female spotted seatrout were ages 0 to 8 and males were ages 0 to 9 Age 1 and 2 spotted seatrout dominated age composition for each bay (Figure 6.4). Generally, few spotted seatrout older than 3 years were collected from the study area. A high degree of variation in observed size at age was evident across all age classes in male and female spotted seatrout (Tables 6.1 and 6.2). Mean fork

TABLE 6.1
Mean Fork Length (FL) and Size Range of Female Spotted Seatrout Collected from Perdido, Pensacola, Choctawhatchee, St. Andrew, St. Joseph, and Apalachicola Bays

Age Class	Perdido Bay			Pensacola Bay			Choctawhatchee Bay		
	N	Mean FL	Range	N	Mean FL	Range	N	Mean FL	Range
0	1	202.0	•	•	•	•	26	254.6	201–315
1	56	324.7	242–490	96	296.3	235–426	72	311.8	209–420
2	63	413.4	324–499	135	409.0	327–526	64	390.3	277–469
3	2	500.0	376–624	73	485.5	350–605	28	468.7	289–562
4	2	512.5	511–514	47	536.9	410–740	7	555.7	502–583
5	1	605.0	•	7	601.3	545–790	4	557.5	542–565
6		•	•	1	617.0	•	1	614	•
Age Class	**St. Andrew Bay**			**St. Joseph Bay**			**Apalachicola Bay**		
	N	**Mean FL**	**Range**	**N**	**Mean FL**	**Range**	**N**	**Mean FL**	**Range**
0	31	253.3	198–311	73	277.4	171–334	13	278.4	231–321
1	252	297.6	189–431	125	340.8	268–460	226	325.6	217–420
2	263	377.8	286–495	46	433.9	292–511	277	391.6	325–498
3	57	447.4	357–560	6	513.3	485–541	92	438.5	380–524
4	55	514.9	376–620	9	581.2	551–610	12	501.5	381–587
5	30	578.3	504–651	8	591.9	535–660	3	561.7	541–593
6	19	624.5	553–715	1	609.0	•	•	•	•
7	3	573.3	497–633	•	•	•	•	•	•
8	1	644.0	•	1	721.0	•	•	•	•

length at age 1 ranged from 296 to 325 mm FL for females and 296 to 289 mm FL for males. By age 3, mean fork length ranged from 289 to 624 mm FL for females and 300 to 489 mm FL for males.

It was determined that, after age 1, growth of male spotted seatrout in the Panhandle region of Florida is best described as linear. Plots of raw length-at-age data for male spotted seatrout showed no apparent asymptote (Figure 6.5). Nonlinear procedures (i.e., NLIN; SAS Institute, Inc., 1988) to fit male spotted seatrout data to von Bertalanffy growth models failed to converge for Pensacola Bay, Choctawhatchee Bay, and St. Andrew Bay (Table 6.3). Male data from Pensacola Bay and Choctawhatchee Bay failed to converge in the Gompertz model (Table 6.4). In addition, asymptotic confidence intervals were extremely broad, with unrealistic upper limits for some fits.

The growth model best suited for female spotted seatrout in the Panhandle of Florida was less clear. The von Bertalanffy and Gompertz models converged for female spotted seatrout data from each bay system (Tables 6.5 and 6.6). However, sample sizes of older age classes were small. As a result, 95% confidence limits for the L_∞ parameter, an estimate of maximum size, were broad. Comparisons of nonlinear growth models or parameters were considered unreliable because the

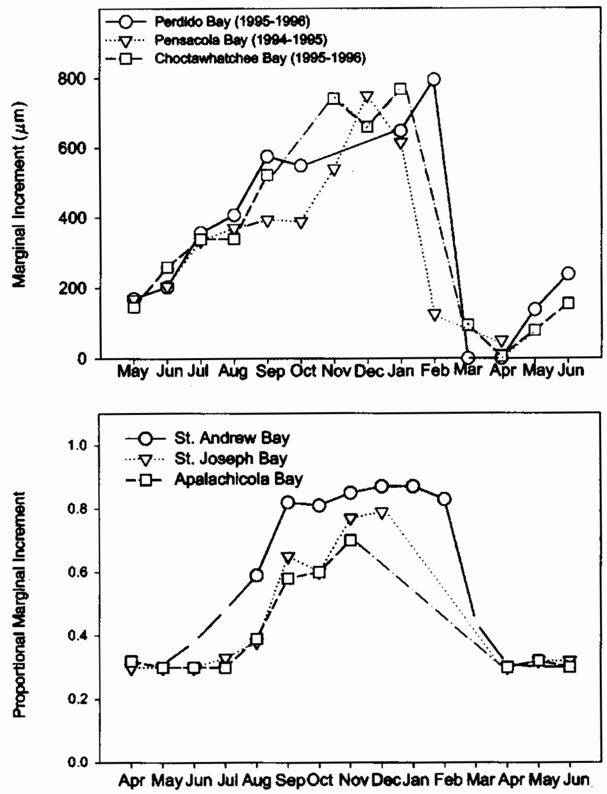

FIGURE 6.3 Marginal-increment growth of sagittal otoliths plotted by month for spotted seatrout collected from the Florida Panhandle. Note different scales of *y*-axes. Marginal increment growth of spotted seatrout otoliths from Perdido Bay, Pensacola Bay, and Choctawhatchee Bay were measured in micrometers (µm). Each sagittal otolith from spotted seatrout collected from St. Andrew Bay, St. Joseph Bay, and Apalachicola Bay was given a value of 0.3, 0.6, or 0.9, based on whether incremental growth from the most recent annulus was less than 1/3, greater than 1/3 and less than 2/3, or greater than 2/3 the distance between the previous two annuli, respectively.

model was heavily influenced by small sample sizes in the upper age range. Therefore, statistical comparisons were made on length–age linear regressions of female spotted seatrout through age 3 (Figure 6.6).

Nine of the fifteen slope comparisons among bays for female spotted seatrout length-age regressions were significantly different (Table 6.7). Male spotted seatrout from Apalachicola Bay had a significantly slower growth rate than spotted seatrout from all other bays. Male spotted seatrout from St. Joseph Bay displayed a significantly faster growth rate than spotted seatrout from all other bays except Perdido Bay. Males from St. Andrew Bay and Perdido Bay grew significantly faster than males from Pensacola Bay and Choctawhatchee Bay. The sample size of females from Perdido Bay warrants attention, however, and comparisons among Perdido Bay females and the other bay systems may not be appropriate.

Slope-elevation (*y*-intercept) comparisons of those length–age regressions with equivalent slopes showed that male spotted seatrout from St. Joseph Bay were significantly larger at age than males from Perdido Bay. Males from St. Andrew Bay were smaller at age than Perdido Bay and Choctawhatchee Bay males. There was no significant difference in length–age regressions for male spotted seatrout from Pensacola Bay and Choctawhatchee Bay.

Nine of the 15 slope comparisons were significantly different among bays for female spotted seatrout length–age regressions (Table 6.8). Female spotted seatrout from Apalachicola Bay grew significantly slower than spotted seatrout from all other bays. Females from St. Joseph Bay grew significantly faster than females from all bays except Perdido and Pensacola bays. Pensacola Bay females grew faster than females from all bays except St. Joseph Bay and Perdido Bay. Female spotted seatrout from Perdido Bay showed equivalent rates of growth with females from all other bays except Apalachicola Bay.

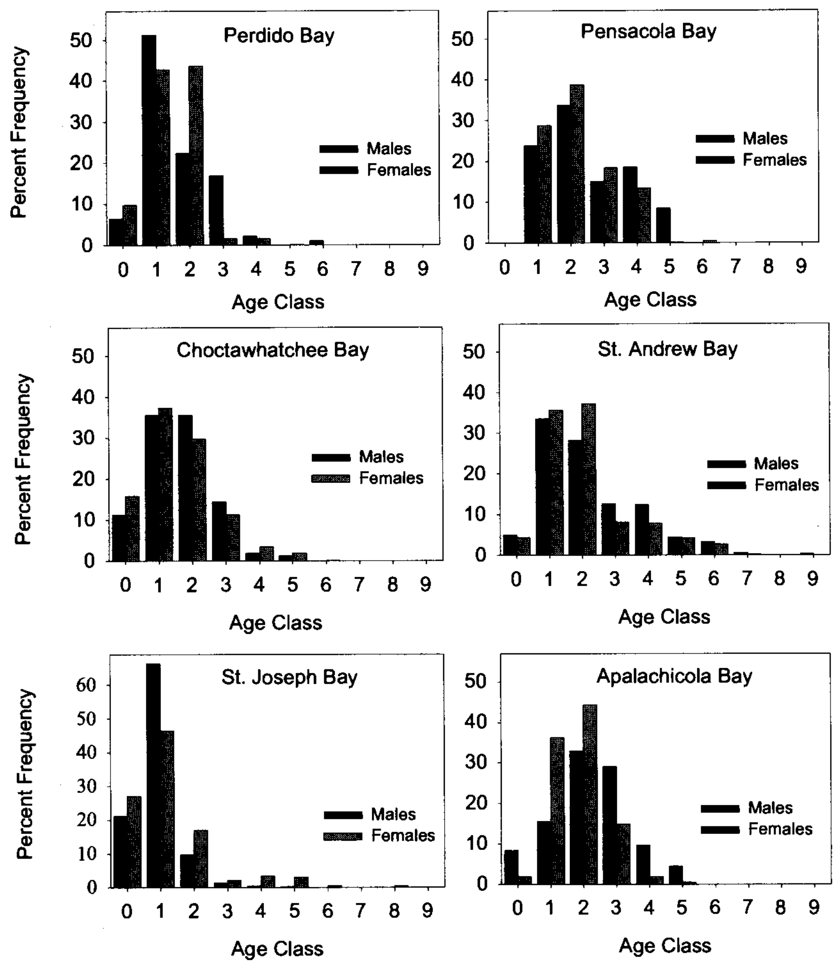

FIGURE 6.4 Age distribution of male and female spotted seatrout from Perdido Bay, Pensacola Bay, Choctawhatchee Bay, St. Andrew Bay, St. Joseph Bay, and Apalachicola Bay.

Slope elevation comparisons of those length-age regressions with equivalent slopes showed that females from Perdido Bay were larger at age than females from St. Andrew Bay, Choctawhatchee Bay, and Pensacola Bay, but smaller at age than females from St. Joseph Bay, which were also larger at age than females from Pensacola Bay. Finally, Choctawhatchee Bay females were larger at age than females from St. Andrew Bay.

Our second method of comparing growth compared mean sizes at individual age classes using bootstrap, resampling analyses. Most of the differences in mean size at age were found at ages 1 and 2 (Table 6.9). Male spotted seatrout from St. Joseph Bay were significantly larger at age 1 than males from all other bays except Apalachicola Bay. By age 2, St. Joseph Bay males were significantly larger than males from all other bays. Mean length of age 1 males from Perdido Bay was either less than or showed no significant difference from age 1 males of other bays; however, by age 2, Perdido Bay males were significantly larger than in all other bays, with the exception of St. Joseph Bay. Age 1 and age 2 males from Pensacola Bay and St. Andrew Bay showed no significant difference in length or were significantly smaller than males from all other bays.

TABLE 6.2
Mean Fork Length (FL) and Size Range of Male Spotted Seatrout Collected from Perdido, Pensacola, Choctawhatchee, St. Andrew, St. Joseph, and Apalachicola Bays

Age Class	Perdido Bay			Pensacola Bay			Choctawhatchee Bay		
	N	Mean FL	Range	N	Mean FL	Range	N	Mean FL	Range
0	•	•	•	•	•	•	10	262.6	236–308
1	37	280.9	220–382	54	272.7	202–331	55	289.3	221–376
2	36	349.0	288–461	76	316.5	237–403	62	325.9	218–402
3	18	397.1	351–441	33	345.5	301–451	28	378.3	320–489
4	2	440.5	436–445	43	394.7	311–503	3	392.0	360–436
5	1	•	•	18	447.7	386–526	2	473.0	471–475
6	1	472.0	•	2	477.0	411–543	•	•	•
7	•	•	•	1	534.0	•	•	•	•

Age Class	St. Andrew Bay			St. Joseph Bay			Apalachicola Bay		
	N	Mean FL	Range	N	Mean FL	Range	N	Mean FL	Range
0	25	250.9	180–307	62	274.7	201–332	13	265.8	230–291
1	170	264.7	197–368	194	310.5	242–407	24	310.3	237–371
2	134	314.0	239–474	29	374.4	261–437	51	338.3	305–385
3	62	376.3	300–485	4	412.0	378–445	45	360.5	315–417
4	62	394.7	312–523	1	485.0	•	15	392.3	335–436
5	22	477.1	373–615	2	516.5	497–536	7	419.4	355–506
6	15	519.0	433–578	•	•	•	•	•	•
7	2	529.0	520–538	•	•	•	•	•	•
8	•	•	•	•	•	•	•	•	•
9	1	586.0	•	•	•	•	•	•	•

St. Joseph Bay female spotted seatrout were significantly larger at ages 1 and 2 than all other females except those from Perdido Bay. Females from St. Andrew Bay were significantly smaller at age1 than females from Perdido Bay, St. Joseph Bay, and Apalachicola Bay and, by age 2, St. Andrew Bay females were significantly smaller than all females except those from Choctawhatchee Bay. Females from Choctawhatchee Bay were significantly smaller at ages 1 and 2 than females from St. Joseph Bay and significantly smaller at age 2 than Perdido Bay females.

DISCUSSION

Growth Models

The maximum observed ages of spotted seatrout reported in this study (5 to 9 for males, 5 to 8 for females) are similar to those in studies from other areas of Florida. Sample size was least in Perdido Bay and only slightly larger in Choctawhatchee Bay. For this reason, maximum age in these bays

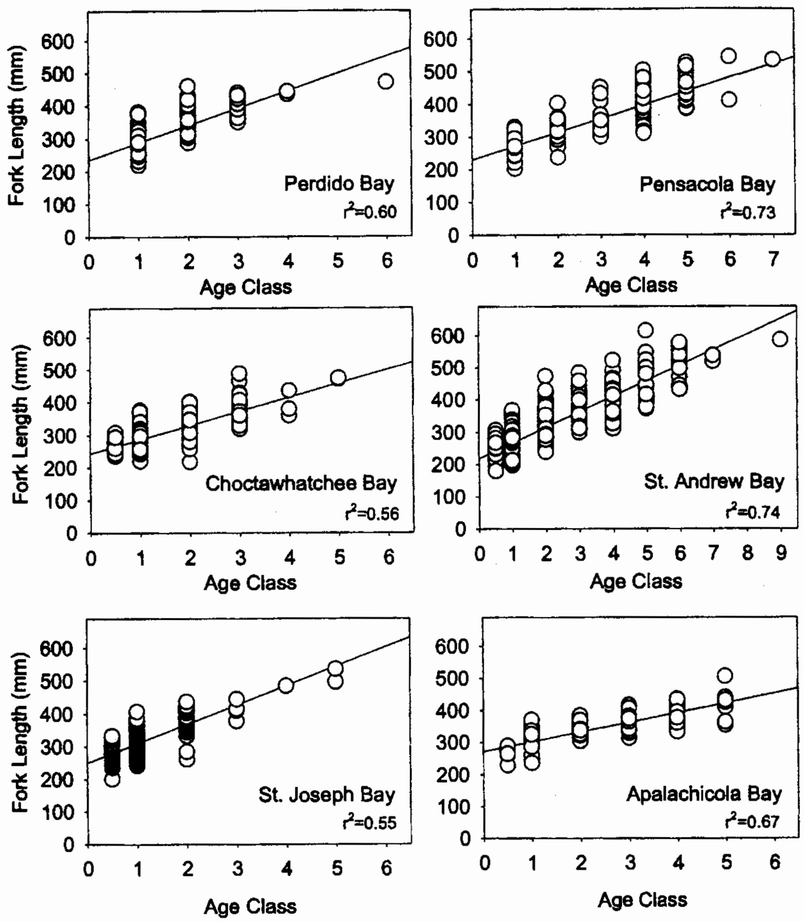

FIGURE 6.5 Plots of length-age regressions for male spotted seatrout from Perdido Bay, Pensacola Bay, Choctawhatchee Bay, St. Andrew Bay, St. Joseph Bay, and Apalachicola Bay.

may be older than reported. Apalachicola Bay is the only bay system in this study for which age and growth of spotted seatrout have previously been reported. Maximum age of 5 years for males and females from Apalachicola Bay in our study is consistent with maximum observed age of 5 and 6 years for males and females, respectively, reported by Murphy and Taylor (1994).

The linear growth after age 1 of male spotted seatrout as described by Murphy and Taylor (1994) is corroborated in this study. The Gompertz and von Bertalanffy equations were not reasonable models to estimate growth of male spotted seatrout in the Florida Panhandle. Plots of observed size at age did not suggest asymptotic growth, and procedures to fit the data to asymptotic models failed to converge in most cases.

Fishes typically do not demonstrate linear growth. Generally, growth is relatively rapid during early years, slows over succeeding years, and then becomes less apparent during senescence. The inability to fit male spotted seatrout data to asymptotic growth curves, coupled with the low number of observations of older spotted seatrout in the Florida Panhandle, suggests that attributes of growth and natural mortality of some populations may be such that asymptotic growth is difficult to detect. Another conclusion may be that, in addition to natural mortality, larger (i.e., older) fish may be selectively harvested from the population such that their numbers are too low for the population to demonstrate asymptotic growth.

TABLE 6.3
Parameter Estimates, Asymptotic Standard Error (ASE), and Upper and Lower (95%) Asymptotic Confidence Intervals (ACIs) of Male Spotted Seatrout Age–Length Data from Perdido, Pensacola, Choctawhatchee, St. Andrew, St. Joseph, and Apalachicola Bays, Fit to von Bertalanffy Growth Model

Bay System	von Bertalanffy				
	Parameter	Estimate	ASE	ACI	
				Lower	Upper
Perdido Bay	L_∞	696.89	128.47	442.62	951.22
	k	0.28	0.12	0.04	0.52
	t_0	-1.21	0.13	-0.23	0.57
Pensacola Bay	L_∞	628.93	24.32	581.13	676.79
	k	0.54	0.06	0.42	0.65
	t_0	0.46	0.06	0.35	0.58
Choctawhatchee Bay	L_∞	706.89	62.84	583.11	830.74
	k	0.35	0.06	0.24	0.47
	t_0	-1.21	0.22	0.05	0.93
St. Andrew Bay	L_∞	969.35	95.46	781.93	1156.78
	k	0.13	0.02	0.08	0.17
	t_0	-1.8	0.19	-2.17	-1.43
St. Joseph Bay	L_∞	732.29	35.55	662.29	802.29
	k	0.29	0.04	0.22	0.36
	t_0	0.13	0.13	-1.43	-0.91
Apalachicola Bay	L_∞	780.4	139.09	507.25	1053.55
	k	0.15	0.05	0.05	0.26
	t_0	-2.53	0.44	-3.40	-1.67

Several arguments given or cited by Zivkov et al. (1999) offer criticisms of asymptotic growth models. Some of their contentions regard the relationship of the L_∞ and k parameters, the dependency of L_∞ and k on the age of the population, and the fact that asymptotic growth models often overestimate the L_∞ parameter because the models are fitted mostly to young fish. While it is beyond the scope of this chapter to analyze or criticize various growth models, we felt our data were a good example of the arguments given by Zivkov et al. (1999).

The present study had very few older fish in the samples. This, coupled with the high degree of variation in size at age, resulted in broad confidence intervals as well as some unreasonable estimates of the L_∞ parameter for both male and female spotted seatrout. It is possible that growth could be more accurately described and compared in alternative contexts, including those presented by Francis (1996) and Wang and Milton (2000). Therefore, we described growth of spotted seatrout by using descriptive statistics and fitting data to standard asymptotic growth curves, but we chose to compare (and describe) spotted seatrout growth using other methods.

Our first method of comparing spotted seatrout growth uses adjusted mean squares to compare slope and elevation of length–age linear regressions (Zar, 1996). This method was used because a

TABLE 6.4
Parameter Estimates, Asymptotic Standard Error (ASE), and Upper and Lower (95%) Asymptotic Confidence Intervals (ACIs) of Male Spotted Seatrout Age–Length Data from Perdido, Pensacola, Choctawhatchee, St. Andrew, St. Joseph, and Apalachicola Bays, Fit to Gompertz Growth Model

Bay System	Gompertz			ACI	
	Parameter	Estimate	ASE	Lower	Upper
Perdido Bay	L_∞	696.88	128.52	442.58	951.24
	k	0.28	0.12	0.04	0.52
	t_0	-1.21	0.43	-2.06	-0.35
Pensacola Bay	L_∞	677.94	39.81	599.56	756.33
	k	0.34	0.05	0.23	0.45
	t_0	-0.68	0.17	-1.02	-0.35
Choctawhatchee Bay	L_∞	845.38	143.64	562.23	1128.361
	k	0.18	0.06	0.06	-0.29
	t_0	-1.57	0.31	-2.18	-0.96
St. Andrew Bay	L_∞	766.9	34.86	698.49	835.37
	k	0.29	0.02	0.24	0.33
	t_0	0.88	0.14	0.60	1.17
St. Joseph Bay	L_∞	674.46	21.95	631.24	717.69
	k	0.47	0.39	0.39	0.55
	t_0	0.22	0.06	0.10	0.33
Apalachicola Bay	L_∞	664.19	64.76	537.02	791.36
	k	0.29	0.05	0.18	0.40
	t_0	-0.17	0.26	-0.67	0.34

linear model was found to best describe male spotted seatrout growth. Length-age linear regressions of female spotted seatrout were compared through age 3 because so few older fish were observed. Ages 1 to 3 are of most concern because they are representative of the ages harvested from the population. It is also likely that ages 1 to 3 are a close representation of the k parameter, or rate of approach to L_∞, in a von Bertalanffy or Gompertz model of female spotted seatrout in the Panhandle region of Florida.

Our second method of comparing growth of spotted seatrout was simply to compare mean length at age (ages 1, 2, and 3) — one of six methods of age comparison given in Francis (1996). This method was chosen because of its simplicity and ability to complement our first method of comparison by indicating at which age a length–age regression slope might increase or decrease for a particular population.

Estuarine-Specific Differences

Spotted seatrout populations in the estuaries of the Florida Panhandle were found to display differences in rate of growth as well as size at age. Interestingly, the bays with the largest growth disparity in this study are two of the closest in proximity. St. Joseph Bay was found to have the fastest growing (steepest regression slope) as well as the largest size at age in both sexes of spotted seatrout in the Florida Panhandle. Spotted seatrout in Apalachicola Bay, roughly 30 km east of St. Joseph

TABLE 6.5
Parameter Estimates, Asymptotic Standard Error (ASE), and Upper and Lower (95%) Asymptotic Confidence Intervals (ACIs) of Female Spotted Seatrout Age–Length Data from Perdido, Pensacola, Choctawhatchee, St. Andrew, St. Joseph, and Apalachicola Bays, Fit to von Bertalanffy Growth Model

Bay System	von Bertalanffy				
	Parameter	Estimate	ASE	ACI	
				Lower	Upper
Perdido Bay	L_∞	522.61	79.31	365.08	680.15
	k	0.33	0.15	0.02	0.64
	t_0	-1.33	0.61	-2.54	-0.12
Pensacola Bay	L_∞				
	k	failed to converge			
	t_0				
Choctawhatchee Bay	L_∞				
	k	failed to converge			
	t_0				
St. Andrew Bay	L_∞				
	k	failed to converge			
	t_0				
St. Joseph Bay	L_∞	748.19	190.53	373.17	1123.20
	k	0.15	0.08	0.01	0.30
	t_0	-2.46	0.55	-3.54	-1.38
Apalachicola Bay	L_∞	510.57	77.06	358.34	662.82
	k	0.19	0.09	0.01	0.36
	t_0	-3.74	1.11	-5.94	-1.54

Bay, were the slowest growing and attained the smallest size at age in most cases. Both sexes of spotted seatrout in Apalachicola Bay grew as large as or larger than seatrout from other bays by age 1. Growth slowed after age 1 so that rate of growth (over the entire age range for males and through age 3 for females) was significantly slower than in other bays in Florida.

Growth disparities among neighboring estuaries were found across the entire study area. Both sexes of spotted seatrout from Perdido Bay grew faster or were larger at age than those from neighboring Pensacola Bay. Spotted seatrout from St. Andrew Bay displayed different growth patterns than those from Choctawhatchee Bay and St. Joseph Bay. Only male spotted seatrout from Choctawhatchee Bay and Pensacola Bay showed no difference in growth rate, and very few differences were found in size at age for either sex between those bay systems.

HYPOTHESES FOR POSSIBLE CAUSATIVE FACTORS FOR DIFFERENCES IN GROWTH

Gene Exchange

Several researchers have reported varying degrees of genetic isolation among spotted seatrout populations and early genetic work provides an argument for individual "subpopulations." Weinstein and Yerger (1976) tested blood serum and eye lens proteins and determined that each estuary from

TABLE 6.6
Parameter Estimates, Asymptotic Standard Error (ASE), and Upper and Lower (95%) Asymptotic Confidence Intervals (ACIs) of Female Spotted Seatrout Age–Length Data from Perdido, Pensacola, Choctawhatchee, St. Andrew, St. Joseph, and Apalachicola Bays, Fit to Gompertz Growth Model

Bay System	Gompertz				
	Parameter	Estimate	ASE	ACI	
				Lower	Upper
Perdido Bay	L_∞	500.31	57.21	386.67	613.95
	k	0.46	0.15	0.16	0.77
	t_o	-0.18	0.17	-0.52	0.16
Pensacola Bay	L_∞				
	k	failed to converge			
	t_o				
Choctawhatchee Bay	L_∞				
	k	failed to converge			
	t_o				
St. Andrew Bay	L_∞	959.30	178.88	607.82	1310.77
	k	0.14	0.03	0.08	0.19
	t_o	2.85	1.41	0.07	5.63
St. Joseph Bay	L_∞	625.40	83.37	461.31	789.48
	k	0.31	0.08	0.16	0.46
	t_o	-0.14	0.35	-0.84	0.55
Apalachicola Bay	L_∞	486.48	54.73	378.35	594.61
	k	0.26	0.08	0.09	0.43
	t_o	-1.76	0.24	-2.23	-1.29

Florida to Texas contained a discrete population (subpopulation) of spotted seatrout. They noted that the most clearly established case of divergence occurred between populations west of the Mississippi and those on the east coast of Florida.

More recent genetic studies did not find conclusive evidence of isolated populations. Ramsey and Wakeman (1987) investigated enzymes and structural proteins of spotted seatrout from 15 bay systems in the Gulf of Mexico and Atlantic coast of Florida. The results of their study indicated that the population structure of spotted seatrout is best described by an "isolation-by-distance" population model. Similar levels of genetic variability, gene flow, and differentiation in spotted seatrout are reported from Texas and northern Mexico by King and Pate (1992): positive short-distance and negative long-distance correlation of allele frequencies are reported, along with a geographic cline in average individual heterozygosity with degree north latitude and west longitude. In addition, Wiley (1996) examined two polymorphic loci in spotted seatrout from Florida, Virginia, South Carolina, and Georgia and found no evidence of multiple populations in Georgia and South Carolina, although those populations deviated significantly from Florida and Virginia spotted seatrout.

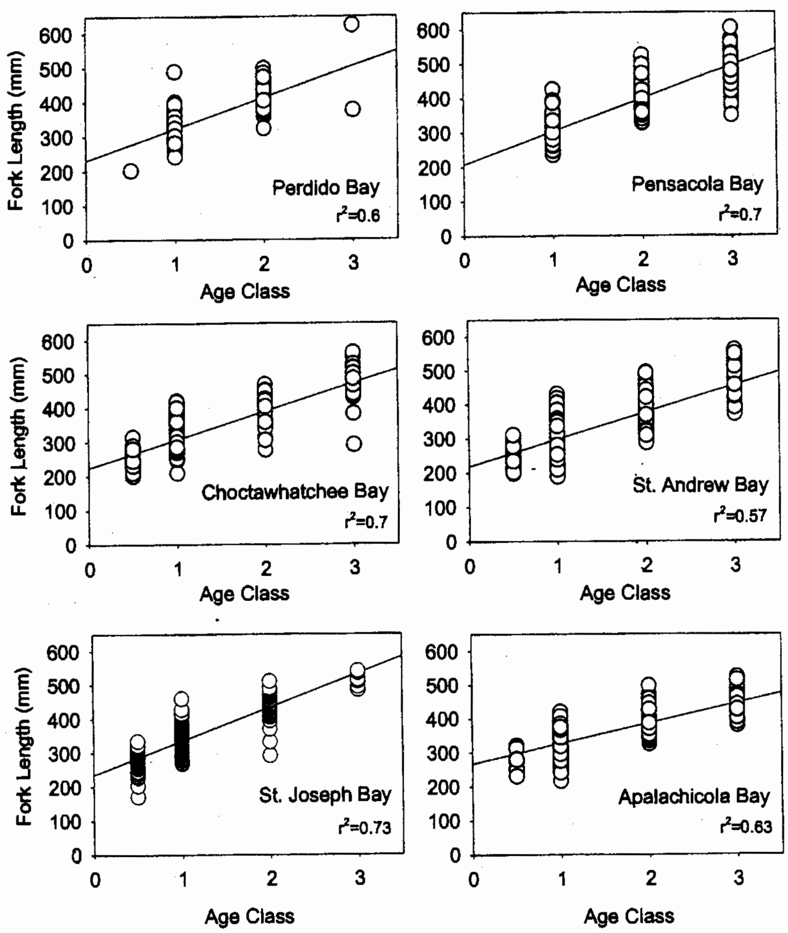

FIGURE 6.6 Plots of length-age regressions (through age 3) for female spotted seatrout from Perdido Bay, Pensacola Bay, Choctawhatchee Bay, St. Andrew Bay, St. Joseph Bay, and Apalachicola Bay.

Sustaining distinct fishery stocks requires a high degree of isolation between populations (Allendorf and Phelps, 1981; King and Pate, 1992). Apparently there is enough gene flow within the spotted seatrout distribution that differentiation into separate genetic stocks has been minor (Ramsey and Wakeman, 1987; King and Pate, 1992; Murphy and Taylor, 1994). Spotted seatrout have been known to make occasional long-distance migrations; a spotted seatrout tagged in Apalachicola, Florida, was recaptured near Grand Isle, Louisiana, more than 500 km (315 miles) from its release site (Moffet, 1961). Seventeen others were recaptured more than 100 km (60 miles) from their release sites (Moffet, 1961). While this behavior is uncommon, the high fecundity of spotted seatrout (Brown-Peterson et al., 1988), coupled with the low degree of genetic variability, allows for the maintenance of homogeneity, which deviates only with long distance separation (Ramsey and Wakeman, 1987; Murphy and Taylor, 1994).

The extensive area of suitable habitat between bay systems facilitates the possibility of movements and gene exchange of spotted seatrout in the Florida Panhandle. All these systems are relatively close together, and all six communicate by way of the Intracoastal Waterway. The portions of this waterway connecting Pensacola Bay communicate with Perdido Bay to the west via Big Lagoon and with Choctawhatchee Bay to the east via Santa Rosa Sound. Big Lagoon and Santa Rosa Sound are natural water bodies and have extensive areas of seagrass meadows.

TABLE 6.7
Results of Student's t-Test of Length–Age Regression Comparisons for Male Spotted Seatrout in the Panhandle Region of Florida

Comparison	Males					
	Slope			Elevation		
	DF	t_value	p_value	DF	t_value	p_value
PDO vs. PNS	318	2.51	p < 0.01	•	•	•
PDO vs. CHC	251	1.83	p < 0.05	•	•	•
PDO vs. SAB	584	0.92	p > 0.10	585	5.5	p < 0.0005
PDO vs. SJB	383	1.24	p > 0.10	384	5.3	p < 0.0005
PDO vs. APB	246	5.33	p < 0.0005	•	•	•
PNS vs. CHC	383	0.41	p > 0.25	384	1.17	p > 0.10
PNS vs. SAB	716	2.81	p < 0.005	•	•	•
PNS vs. SJB	515	4.78	p < 0.0005	•	•	•
PNS vs. APB	378	4.33	p < 0.0005	•	•	•
CHC vs. SAB	649	1.37	p > 0.05	650	4.27	p < 0.0005
CHC vs. SJB	448	3.66	p < 0.0005	•	•	•
CHC vs. APB	311	3.73	p < 0.0005	•	•	•
SAB vs. SJB	781	2.68	p < 0.005	•	•	•
SAB vs. APB	644	6.06	p < 0.0005	•	•	•
SJB vs. APB	443	7.98	p < 0.0005	•	•	•

Bay System	Length–Age Regression Equation
Perdido Bay (PDO)	FL = 235.67 + 52.57 (AGE)
Pensacola Bay (PNS)	FL = 230.58 + 41.57 (AGE)
Choctawhatchee Bay (CHC)	FL = 243.71 + 42.97 (AGE)
St. Andrew Bay (SAB)	FL = 218.68 + 48.10 (AGE)
St. Joseph Bay (SJB)	FL = 250.40 + 58.08 (AGE)
Apalachicola Bay (APB)	FL = 272.32 + 30.23 (AGE)

The Intracoastal Waterway connecting Choctawhatchee, St. Andrew, St. Joseph, and Apalachicola bays is a series of natural rivers and manmade canals. The habitat suitability between these systems is not as good as that in the western portion of the Intracoastal Waterway. However, movement between these systems remains possible, especially during winter when spotted seatrout move into rivers to avoid rapid temperature changes.

Gene exchange of spotted seatrout in the Florida Panhandle may also occur through larval transport between systems. Each bay contains deep, strong flowing channels running between barrier islands in which spotted seatrout frequently spawn (Saucier and Baltz, 1993). The close proximity of each bay system and the frequency of natural and manmade passes between them may allow currents to carry various stages of developing eggs and larvae into a new system.

TABLE 6.8
Results of Student's t-Test of Length–Age Regression Comparisons for Female Spotted Seatrout in the Panhandle Region of Florida

	Females					
Comparison	Slope			Elevation		
	DF	t_value	p_value	DF	t_value	p_value
PDO vs. PNS	422	0.54	$p > 0.10$	423	3.22	$p < 0.001$
PDO vs. CHC	308	1.09	$p > 0.10$	309	3.95	$p < 0.0005$
PDO vs. SAB	721	1.50	$p > 0.05$	722	6.85	$p < 0.0005$
PDO vs. SJB	368	1.14	$p > 0.10$	369	2.85	$p < 0.0025$
PDO vs. APB	726	5.28	$p < 0.0005$	•	•	•
PNS vs. CHC	490	2.42	$p < 0.01$	•	•	•
PNS vs. SAB	903	3.69	$p < 0.000$	•	•	•
PNS vs. SJB	550	0.69	$p > 0.25$	551	7.07	$p < 0.0005$
PNS vs. APB	908	9.89	$p < 0.0005$	•	•	•
CHC vs. SAB	789	0.47	$p > 0.25$	790	3.01	$p < 0.0025$
CHC vs. SJB	436	3.06	$p < 0.001$	•	•	•
CHC vs. APB	794	6.03	$p < 0.0005$	•	•	•
SAB vs. SJB	849	3.80	$p < 0.0005$	•	•	•
SAB vs. APB	1207	5.90	$p < 0.0005$	•	•	•
SJB vs. APB	854	9.75	$p < 0.0005$	•	•	•

Bay System	Length–Age Regression Equation
Perdido Bay (PDO)	FL = 231.42 + 91.29 (AGE)
Pensacola Bay (PNS)	FL = 207.58 + 95.72 (AGE)
Choctawhatchee Bay (CHC)	FL = 224.56 + 82.52 (AGE)
St. Andrew Bay (SAB)	FL = 218.65 + 79.09 (AGE)
St. Joseph Bay (SJB)	FL = 235.41 + 99.59 (AGE)
Apalachicola Bay (APB)	FL = 267.60 + 59.60 (AGE)

Fishing Pressure and Habitat

Murphy and Taylor (1994) concluded that differences in growth rate among Charlotte Harbor, Apalachicola, and Indian River spotted seatrout were independent responses to local fishing pressures, which probably affect growth of spotted seatrout in the Florida Panhandle, as well. In addition, habitat differences may interact with local fishing pressure. Some bays in our study, such as Perdido Bay and Apalachicola Bay, are very turbid. Locating suitable fishing areas without intimate local knowledge of these bays is difficult. Collection of spotted seatrout by our staff was hindered in those systems for this reason.

Other bays, such as St. Joseph and portions of Choctawhatchee and St. Andrew, are clear with extensive areas of seagrass meadows that facilitate location of suitable habitat by fishers. The interaction of habitat differences and types of fishing pressure may cause the effects of pressure to vary.

TABLE 6.9
P-Values for Mean Length-at-Age Bootstrapped Analyses, Mean, and Standard Deviations by Age Class of Male and Female Spotted Seatrout

Comparison	Males Age Class 1	Males Age Class 2	Males Age Class 3	Females Age Class 1	Females Age Class 2	Females Age Class 3
PDO vs. PNS	0.8667	0.0001	0.0001	0.0013	0.9717	0.9969
PDO vs. CHC	0.8554	0.0179	0.4146	0.5412	0.0090	0.9149
PDO vs. SAB	0.9940	0.0001	0.1848	0.0003	0.0001	0.5957
PDO vs. SJB	0.0001	0.0385	0.9618	0.1811	0.0643	0.9998
PDO vs. APB	0.0149	0.7058	0.0026	1.0000	0.0009	0.3535
PNS vs. CHC	0.1180	0.6000	0.0033	0.1844	0.1620	0.4944
PNS vs. SAB	0.6569	0.9962	0.0007	0.9998	0.0001	0.0007
PNS vs. SJB	0.0001	0.0001	0.0038	0.0001	0.0027	0.6461
PNS vs. APB	0.0003	0.0066	0.3578	0.0001	0.0002	0.0001
CHC vs. SAB	0.0002	0.2193	0.9998	0.1257	0.2605	0.4448
CHC vs. SJB	0.0010	0.0001	0.3997	0.0001	0.0001	0.2071
CHC vs. APB	0.1216	0.3922	0.2294	0.1656	0.9997	0.0243
SAB vs. SJB	0.0001	0.0001	0.2970	0.0001	0.0001	0.0172
SAB vs. APB	0.0001	0.0003	0.1512	0.0001	0.0023	0.5892
SJB vs. APB	1.0000	0.0002	0.0430	0.0197	0.0001	0.0002

Bay System	Males Age Class 1 Mean / Std Dev	Males Age Class 2 Mean / Std Dev	Males Age Class 3 Mean / Std Dev	Females Age Class 1 Mean / Std Dev	Females Age Class 2 Mean / Std Dev	Females Age Class 3 Mean / Std Dev
Perdido Bay (PDO)	280.92	348.97	397.11	324.71	413.40	500.00
	39.74	42.20	28.97	42.37	32.43	175.36
Pensacola Bay (PNS)	272.72	316.51	345.48	296.30	408.98	485.53
	24.51	23.97	31.93	33.61	51.11	50.75
Choctawhatchee Bay (CHC)	289.27	325.87	378.29	311.84	390.28	468.71
	35.16	33.50	40.51	48.22	39.02	53.87
St. Andrew Bay (SAB)	264.73	313.99	376.32	297.60	378.84	450.35
	38.64	41.90	40.15	52.77	40.18	51.45
St. Joseph Bay (SJB)	310.49	374.38	412.00	340.81	433.87	513.33
	32.13	37.90	27.43	37.62	38.28	22.02
Apalachicola Bay (APB)	310.29	338.29	360.49	325.63	391.59	438.51
	32.50	14.69	19.84	35.68	30.73	28.39

Systems such as Apalachicola Bay, a turbid system with a high concentration of fishing guides and low (human) population density, may show different impacts from pressure than systems such as St. Joseph Bay, where water clarity and habitat characteristics make it easier for less knowledgeable fishers to catch fish effectively, or Pensacola or St. Andrew Bay, which are more urban and have larger numbers of fishers living in the area.

Subtle differences in habitat types among the bay systems may also cause differences in growth rate by indirectly affecting interspecific and intraspecific food partitioning. In other words, community assemblages associated with each habitat type may differ and, as a result, interference competition from other species or size classes may influence growth rates of spotted seatrout. Lack of competition resulting from lower population densities in some bay systems may also influence growth rates.

Interannual Variability

Fish collections in this study were not all made in the same year. As a result, differences in spotted seatrout growth among bay systems may be attributable to annual variability. Environmental variables such as rainfall and river flows may affect larval growth and mortality, and variation in annual temperatures may affect the length of the growing season. Optimum salinity and temperatures have been reported for the survivability of larval spotted seatrout. Taniguchi (1981) and Banks et al. (1991) reported that age-linked changes in salinity tolerances occur in the larval stage. If larval fish are stressed by suboptimal temperature or salinity, slower growth may result and be reflected in smaller size at later age.

CONCLUSIONS

Variation in growth between estuarine systems as reported in this study is characteristic of spotted seatrout populations (Moody, 1950; Moffet, 1961; Iversen and Tabb, 1962; Murphy and Taylor, 1994). Many factors may explain differences in growth of spotted seatrout among bay systems, including but not limited to genetic isolation of populations, differences in habitat or water quality during one or more life history stages, and differences in fishing pressure. The causes for differences in growth may have significant relevance to measures of environmental differences between regions. Moreover, the actual differences in growth of spotted seatrout between bay systems should be pertinent to management applications. Immediately relevant to fisheries management is the integration of estuary-specific growth information, spawning potential ratios, and genetic characteristics with landings data.

Florida addressed this issue in 1995 when it implemented a regional management plan for the spotted seatrout fishery — an important step in spotted seatrout management. Since the implementation of the regional plan, regulations of the spotted seatrout fishery have been adjusted at least twice based on estuary-specific information. Much work is still needed, however; user-group conflicts exist among regions, with some claiming that there are no data from their region. Other problems with spotted seatrout management are the high cost of obtaining meaningful data, the time lag between data collection and stock assessment, and the need for better communication among user groups and managers.

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